## Amendments To Specification Paragraphs

Replace paragraph [0016] with the following amended version. This will remove mentions of plural devices added earlier in Amendment B that were to correspond with the proposed, but refused, drawing changes:

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**[0016]** FIG. 1 shows how varying the widths of face-to-face grooves, and alignment with a sliding, even slightly rotatable, fiber key, can facilitate the tuning of coupling efficiency in a 4-port fiber-optic apparatus ~~efficiencies in an array of 4-port fiber-optic apparatuses~~ made with side-polished fibers. ~~The array is shown also having multiple 2-port fiber-optic apparatuses.~~

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Replace paragraph [0025] with the following amended version. This will a) place a period immediately after "FIG" and before "1B" in the first line and b) remove those mentions of plural devices added earlier in Amendment B that were to correspond with the proposed, but refused, drawing changes and add back in those that were in the first version as originally filed.

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**[0025]** Reference is now made to FIG. 1, which consists of two parts, FIG. 1A and FIG. 1B ~~FIG 1B~~. FIG. 1 shows ~~multiple 4-port and 2-port fiber-optic apparatuses arranged in an array, wherein multiple 4-port fiber-optic apparatuses can be tuned by translation and/or rotation constrained by an alignment-keying fiber. Thus the~~ art presented and claimed in the copending U.S. patent application titled "Structures and Methods for Aligning Fibers", by Tullis, now issued as US Pat. No. 6,516,131~~, for aligning a single 4-port apparatus is expanded for aligning arrays of 4-port apparatuses~~. FIG. 1 shows how varying the widths of face-to-face grooves ~~to create tapered channels~~, as well as alignment with a ~~by~~ sliding ~~with a~~ fiber key (called an alignment fiber) ~~in one of these channels~~, can facilitate the tuning of coupling efficiency between two fibers within a 4-port apparatus ~~within multiple 4-port apparatuses~~. This ~~Each~~ 4-port apparatus can be any of the group including couplers, add-drop multiplexers, taps, splitters, joiners, filters, modulators and switches. The tuning is accomplished by adjusting the interaction length between two evanescently coupled fibers. Although only a single 4-port apparatus is shown, one can easily envision multiple

4-port apparatuses constructed side-by-side within the same two substrates. And additional alignment grooves and their alignment fibers may also be included.

Replace paragraph [0026] with the following amended version. This will remove earlier changes that were made to correspond with proposed, but refused, changes to FIG. 1A and FIG. 1B. This new version is identical to the first version as originally filed with the exceptions that a) a hyphen has been added between fiber and optic in two places and b) the phrase "which serves as an alignment fiber" has been inserted at the end of the seventh sentence in keeping with usage found in the ninth sentence and the incorporated patent, US Pat. No. 6,516,131.

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**[0026]** FIG. 1A shows a tunable 4-port fiber-optic apparatus 1, such as a coupler or add-drop multiplexer. This 4-port apparatus 1 is comprised of two half-couplers 2 and 3 comprised in turn of respective side-polished fibers 4 and 5 installed within respective varying-width V-grooves 6 and 7 etched into 100 crystal surfaces 8 and 9 respectively (shown face-to-face) of respective substrates 10 and 11. The two substrates can be slid over one another in the direction parallel to the long axes (not shown) of the two side-polished areas 12 and 13. The two side-polished areas 12 and 13 are shown at a position where they overlap one another. The side-polished areas 12 and 13 of the fibers 4 and 5 have an elliptical shape with long axes parallel to the groove axes (not shown). The arrows 14 and 15 indicate the direction of motion desired. The apparatus 1 is additionally comprised of a third fiber 16 which serves as an alignment fiber. Fiber 16 is in a bi-directionally tapered channel 17 constructed of two additional varying-width V-grooves 18 and 19 etched into the surfaces 8 and 9, parallel to grooves 6 and 7 but offset from them. Fiber 16 serves as an alignment key within this channel 17, but allows for the motion described with which to tune the coupling ratio and efficiency of the 4-port assembly. By eliminating any linear portion to the channel 17, the two half-couplers 2 and 3 may be allowed some rotation which is easy to control with the substrates being of a significant scale larger than the side-polished areas, but remain well aligned in the direction of offset just described. Yet another advantage of the bi-directionally tapered channels 17 and that formed by grooves 6 and 7, is that the fibers 16, 4 and 5 will experience less chance to be bent and strained entering or leaving the channel 17 than were it of constant cross-section. The taper at the ends of these

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channels can be accentuated to help achieve additional avoidance of strain on the fibers 16, 4 and 5 from otherwise being bent about a sharp edge. It is important in high-bandwidth fiber-optic applications, such as in modern data- and telecommunications networks, to avoid straining fibers. This is because strain induces birefringence in the fiber and this causes polarization mode-dispersion that can result in high bit-error-rates. ~~FIG. 1A shows a tunable array of 4-port fiber-optic apparatus 1 interspersed with 2-port fiber-optic apparatuses. The 4-port fiber-optic apparatuses may not be all alike; for example one may be a coupler, while another might be an add-drop multiplexer. The 2-port fiber-optic apparatuses 5A and 5C may not be all alike; for example one may be a polarizer, while another might be an attenuator. The array of 4-port apparatuses 1 is comprised of two arrays of half-couplers 2 and 3. Each of these two arrays of half-couplers 2 and 3 is comprised of side-polished fibers installed within respective varying-width V-grooves, for example etched into 100 crystal surfaces. A first array of half-couplers 2 is shown comprised of a substrate 10 having a surface 8 containing varying-width grooves 6, 6A, and 6B. A second array of half-couplers 3 is shown comprising a substrate 11 having a surface 9 containing varying-width grooves 7, 7A, 7B, and 7C. The two substrates 10 and 11 are placed with their respective surfaces 8 and 9 face-to-face with the grooves of one aligned at least approximately with grooves of the other. The two substrates can be slid over one another in the direction parallel to the long axes (axes not shown) of the side-polished areas 12, 13, 12B, and 13B. The two side-polished areas 12 and 13 are shown at a position where they overlap one another, as are the two side-polished areas 12B and 13B. The side-polished areas 12, 12B, 13, 13A, 13B, and 13C each have an elliptical shape with long axes parallel to the groove axes (not shown). The arrows 14 and 15 indicate the direction of motion desired. The side-polished areas of the fibers 5A and 5C don't have matching areas of another fiber to overlap, however notice that the side-polished area of fiber 5A has a region of space above it created by the groove 6A that lies above it, whereas the side-polished area of fiber 5C doesn't have a groove above it and thus faces the surface 8 of substrate 10. The space above the fiber 5A and its side-polished area 13A, that is the space within the groove 13A would be filled with a gas, a liquid, a fluid containing one or more bubbles, or a solid filler material. The apparatus 1 is additionally comprised of a third fiber 16 which serves as an alignment fiber. Fiber 16 is in a bi-directionally tapered~~

~~channel 17 constructed of two additional varying-width V-grooves 18 and 19 etched into the surfaces 8 and 9, parallel to grooves 6 , 7, 6B, and 7B but offset from them. Fiber 16 serves as an alignment key within this channel 17, but allows for the motion described with which to tune the coupling ratio and efficiency of the 4-port assembly. By eliminating any linear portion to the channel 17, the two half couplers 2 and 3 may be allowed some rotation which is easy to control with the substrates being of a significant scale larger than the side-polished areas, but remain well aligned in the direction of offset just described. One skilled in the art will immediately appreciate that a sliding action along an alignment fiber, or along possibly multiple and parallel alignment fibers, can tune an array of 4-port side-polished fiber-optic apparatuses. And one skilled in the art will also immediately appreciate that a relative rotation of the two substrates, constrained by one or more alignment fibers in their respective and parallel bi-directionally tapered channels, will affect the tune of a 4-port fiber-optic apparatus more, the more distant it is from a center of rotation. This is useful, for example, to optically compensate for a gradient in sidewall thickness often existing across an array of optical fibers. Yet another advantage of the bi-directionally tapered channels 17 and those formed by grooves 6 and 7, 6A and 7A, 6B and 7B, and by 7C alone is that the fibers 16 alone, 4 and 5, 5A alone, 4B and 5B, and 5C alone will experience less chance to be bent and strained entering or leaving their respective channels than were the channels of constant cross-section. The taper at the ends of these channels can be accentuated to help achieve additional avoidance of strain on the fibers 16, 4 and 5 from otherwise being bent about a sharp edge. It is important in high-bandwidth fiber-optic applications, such as in modern data- and telecommunications networks, to avoid straining fibers. This is because strain induces birefringence in the fiber and this causes polarization mode-dispersion that can result in high bit-error-rates.~~

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Replace paragraph [0027] with the following amended version. This will remove earlier changes that were made to correspond with proposed, but refused, changes to FIG. 1A and FIG. 1B, but will retain some improvements to readability.

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**[0027]** FIG. 1B shows an end-view of the apparatus illustrated in FIG. 1A with all similar parts identified by the same numbers, except the view is as though the fibers 16, 4, and 5~~4, 4B,~~

~~5, 5A, 5B, 5C, and 16~~ were terminated at the midpoints of the channels. In addition, the cores ~~, such as~~ 20 and 21 to fibers 4 and 5 respectively, are depicted as shaded disks or spots. Note how in this view, the interface between the two side-polished areas 12 and 13 ~~(and between the two side-polished areas 12B and 13B)~~is a region of mutual contact. And note for example, how the side-polish on the fibers 4 and 5 has allowed the cores 20 and 21 to lie closer to one another to cause better evanescent coupling of light waves between the two cores 20 and 21.

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Replace paragraph [0045] with the following amended version. This restores the paragraph to the first version as originally filed, and thus will remove changes that were made to correspond with proposed, but refused, changes to FIG. 3.

**[0045]** In FIG. 3, a substrate 70 is shown in a plan view 71, a side-view 72, and an end-view 73. Two arcuate grooves 74 and 75 are shown, and three straight grooves 76,77, and 78 are shown, in an alternating sequence within surface 81. All the grooves 75 through 78 are parallel to one another. Preferably, the widths and depths of the straight grooves 76, 77, and 78 are equal to or larger than the widths of the arcuate grooves 74 and 75 where the arcuate grooves 74 and 75 reach the ends 79 and 80 of the substrate 70. The surface area left un-etched 81 between these grooves should be minimized in order to facilitate the parting of substrates (31 and 58 in FIG. 2I) placed with these faces (31 and 52 in FIG. 2I; 81 on the substrate illustrated in FIG. 3) touching one another. The substrate 70 illustrated would be able to accept two fibers, one in each arcuate groove. A linear array of more numerous arcuate grooves can be etched into a common substrate, with one or more extra grooves (illustrated as straight grooves in FIG. 3) interleaved between them, but only two arcuate grooves and three extra grooves are illustrated in FIG. 3 for drawing simplicity. As was discussed above, the purpose of the extra grooves is at least two-fold. One such purpose is to act as a barrier against spreading of permanent bonding material when fabricating a freestanding coupler. Another such purpose is to provide air access channels when parting two such surfaces that have been put face-to-face against one another. ~~In FIG. 3, a substrate 70 is shown in a plan view 71, a side-view 72, and an end-view 73. A first group of grooves is shown including two arcuate grooves 74 and 75 and three constant-~~

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~~width grooves 76,77, and 78, in an alternating sequence within surface 81, wherein all the grooves 75 through 78 are parallel to one another. A second group of additional grooves 84, 85, and 86 is shown perpendicular to the first group. Preferably, the widths and depths of the straight grooves 76, 77, and 78 are equal to or larger than the widths of the arcuate grooves 74 and 75 where the arcuate grooves 74 and 75 reach the ends 79 and 80 of the substrate 70. The surface area left un-etched 81 between these grooves should be minimized in order to facilitate the parting of substrates (31 and 58 in FIG. 2I) placed with these faces (31 and 52 in FIG. 2I; 81 on the substrate illustrated in FIG. 3) touching one another. The substrate 70 illustrated would be able to accept two optical side-polished fibers, one in each arcuate groove. A linear array of more numerous arcuate grooves can be etched into a common substrate, with one or more extra parallel grooves (illustrated as constant-width and constant-depth grooves in FIG. 3) interleaved between them, but only two arcuate grooves and three extra parallel grooves are illustrated in FIG. 3 for drawing simplicity. As was discussed above, the purpose of the extra parallel grooves is at least two-fold. One such purpose is to act as a barrier against spreading of permanent bonding material when fabricating a freestanding coupler. Another such purpose is to provide air access channels when parting two such surfaces that have been put face-to-face against one another. Also as discussed above, the purpose of the second group of additional and perpendicular grooves 84, 95, and 86 is to provide channels for access of air (or other fluid), for UV light to cure UV adhesive, and for parting tools, but they too can be used to limit flow of adhesive and reduce the area of bonding between two face-to-face substrates.~~

C5 cont'd.

Replace paragraphs [0002], [0003], [0010], [0013], [0042], [0043], and [0059] with the following amended versions, respectively. In Amendment B, applicants had respectfully requested Examiner to substitute a hyphen for the blank between the two words in "fiber optic" in the following locations, in only one instance per paragraph, but had not been aware that inter-lineation is no longer proper:

Paragraph [0002] at the second and third lines and before the word "apparatuses";

Paragraph [0003] on the fourth line and before the word "apparatuses";

Paragraph [0010] on the fourth line and before the word "apparatuses";

Paragraph [0013] on fourth line and before the word "technology";

Paragraph [0042] on the fourteenth line and before the word "apparatus";
Paragraph [0043] on the third line and before the word "apparatuses";
Paragraph [0059] on the second line and before the word "couplers".

**[0002]** This invention generally pertains to methods for adding process integration to the manufacture of fiber-optic~~fiber optic~~ apparatuses implemented with side-polished fiber optics. This invention also pertains to integrated apparatuses made from these methods of manufacture. Note that the word "apparatus" as used in this disclosure does not mean bare, un-altered, fiber-optic fiber, but rather one or more fiber-optic fibers with at least one of the fibers structurally altered from its original, generally circular or elliptical, cross-sectional shape (e.g. by side-polishing) and/or made to interact optically with another fiber over a finite length of fiber.

**[0003]** There is no prior art method or apparatus published, or on the market, for fully utilizing the advantages of integrated processes with silicon to manufacture side-polished fiber-optic~~fiber optic~~ apparatuses and systems, other than the photomasking of multiple features such as grooves, or the deposition of coatings. What is known in the prior art deals with individually placing fibers in grooves, one-at-a-time. Once placed they may all be polished in one step. This prior art is limited to the manufacture of side-polished fibers to implement two-port photonic functions. This known art is taught in the U.S. patents 5,781,675 "Method for preparing fiber-optic polarizer" and 5,809,188 "Tunable optical filter or reflector", both by Tseng. In those patents, Tseng teaches the use of a set of parallel and variable-depth V-grooves etched in a common silicon crystal substrate to simultaneously achieve both a) precise control of remaining side-wall thickness left on each fiber held within each of the V-grooves, b) arcuate paths for the fibers which enable the side-polished regions to be of a controlled length, and c) simultaneous deposition of one or more films on the set of side-polished regions. Not taught in the above patents are multi-function apparatuses or methods for manufacturing multiple apparatuses on a common fiber without fuse splicing or physical connectors. Also not disclosed are a) methods or apparatuses for fabricating multiple units simultaneously, other than the substrates themselves or 2-port polarizers or filters; b) methods or apparatuses wherein

some multiples of individual apparatuses are formed with at least one fiber in common; or c) any methods or apparatuses for fiber-to-fiber alignment when coupling side-polished areas to one another between fibers in respectively different substrates.

[0010] The current invention goes beyond one-at-a-time fabrication and introduces process integration methods by which to greatly reduce the cost of manufacturing side-polished fiber-optic~~fiber optic~~ apparatuses. Furthermore, the current invention makes possible the integration of compact arrays of side-polished apparatuses that can be used to implement high levels of function integration. And not all of the multiple apparatuses manufactured on a common substrate need be of the same type.

[0013] These and other objects of the invention are provided by a novel use of combining integrated manufacturing methods used in the semiconductor electronics field with silicon-based side-polished fiber-optic~~fiber optic~~ technology. Whole silicon wafers (or wafers of other suitable cubic crystal materials such as Ga-As or Lithium Niobate) are patterned and etched to construct V-grooves at many sites simultaneously in a single masking and etching process level. Then rows of these sites are diced and separated leaving multiple sites within each row or silicon strip. Then parallel fibers are installed and bonded into the V-grooves within a strip, and the side-polishing step is performed on all the fibers within a row or strip in a single polishing operation. Following the polishing step, additional steps can be performed on the side-polished areas to create a range of 2-port apparatuses from the group including an optical pass-through, an attenuator, a polarizer, a filter, a modulator, and a switch. These strips of 2-port apparatuses can then be diced into separate smaller strips, individual fiber units, or left intact as complete arrays. These 2-port strips or individual units can be combined in pairs to form strips or individual units of 4-port apparatuses. And the strips of 2 or 4-port apparatuses can be stacked into 2-dimensional arrays. Within a strip or stack of strips, the individual 2-port and/or 4-port apparatuses can be connected in series and/or parallel to create compact optical circuits.

[0042] The last portion of the process is depicted by FIG. 2I. FIG. 2I shows the substrates 31 and 58 parted, leaving a freestanding, bonded 4-port coupler 59. What is not shown is that

prior to parting the two substrates 31 and 58, the replacement bonding material holding the end portions of the fibers 42 and 54 into place in their respective substrates 31 and 58 is first loosened by a solvent or by heating. As a freestanding 4-port coupler 59, its two fibers 42 and 54 are now affixed together but free of the substrates 31 and 58. Note that the substrates 31 and 58 may now be reused to make yet another such apparatus. This potential reuse of the silicon substrates can significantly lower the cost of producing 4-port couplers. This separation of a fiber-optic~~fiber optic~~ apparatus from a substrate also removes thermal expansion mismatch issues as mentioned in the above referenced US patent 4,475,790 by Little, titled "Fiber optic coupler".

**[0043]** It should be noted that although the above process is described with respect to the formation of a 4-port coupler, other 4-port (or 3-port) fiber-optic~~fiber optic~~ apparatuses can be formed with additional steps to make any of the group including couplers, add-drop multiplexers, taps, splitters, joiners, filters, modulators or switches. For example, the core of the fibers used, in the region of side-polish, can be fiber Bragg gratings, as known in the art. Or one or more films can be deposited on one or more side-polished areas, wherein such one or more films could contain Bragg gratings. Or one or more films deposited or sandwiched between the side-polished areas of two fibers could be an electro-active polymer complete with embedded electrodes for connecting to external drive circuitry.

**[0059]** FIG. 6 shows the batch manufacture 150 of a strip of 4-port fiber-optic~~fiber optic~~ couplers 151 from two strips of 2-port half-couplers 152 and 153. The strips of 2-port half-couplers 152 and 153 can be batch manufactured by the method depicted and described above with reference to FIG. 4, including the steps illustrated and described with reference to FIG. 5. Note that the substrates for the two strips of half-couplers 152 and 153 come from two rows or strips 154 and 155 batch-fabricated from a common wafer 156 that is diced into strips. The more detailed steps are those described above with reference to FIG. 2.